The Science of Die Casting

A Brief Review of The Science That Governs Some of The Major Issues In Die Casting

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What is a simulation?

Laws of Physics

Equations that precisely describes world!

But difficult to solve!

Computer Software

Solves these equations

User Define the Problem

User must

correctly define the problem

to be simulated!

User Interprets Results

Arrive at meaningful conclusions

Propose effective measures to solve the problem

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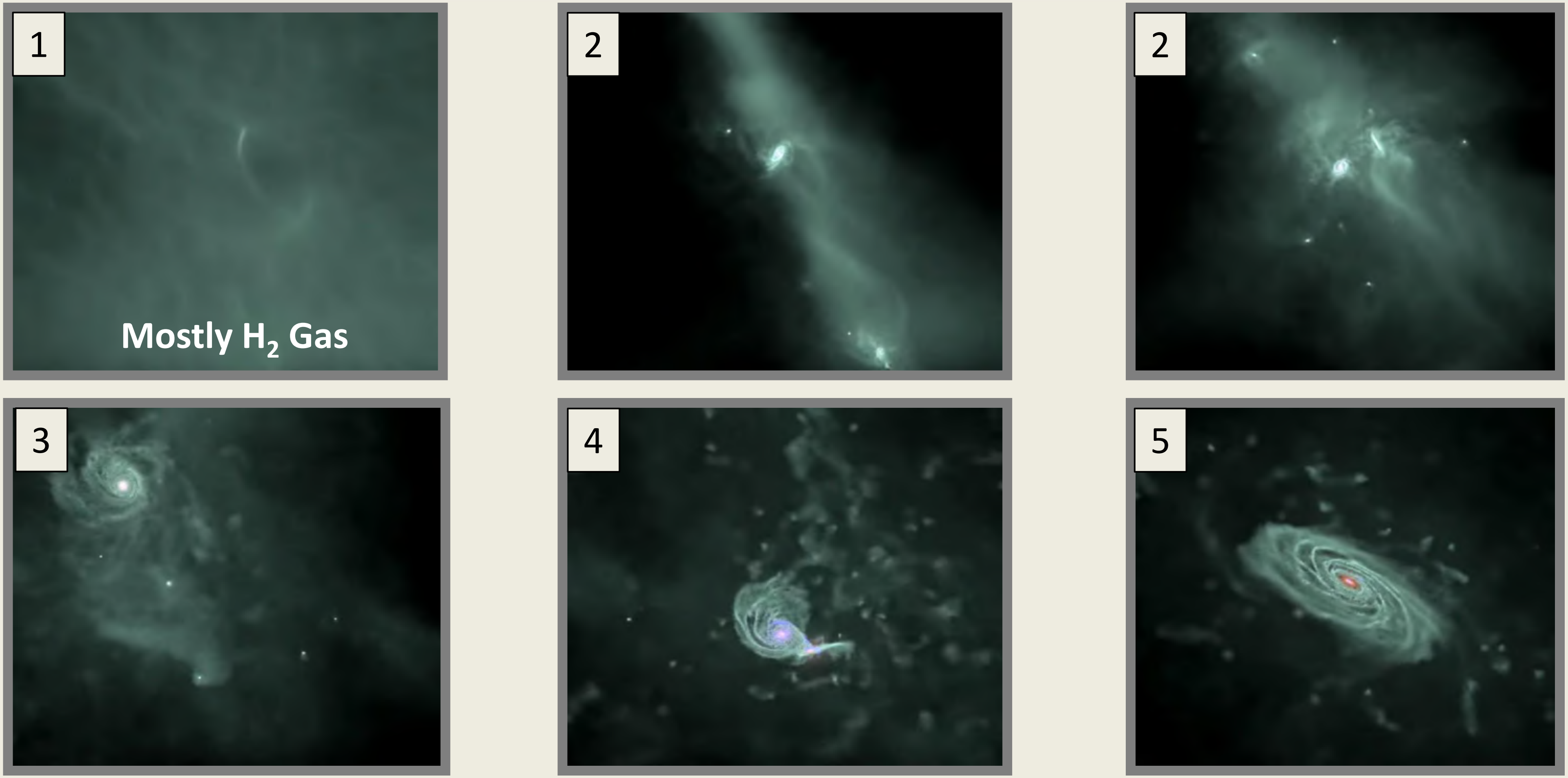
What is a simulation?

Galaxy Formation
Evolution through Billions years

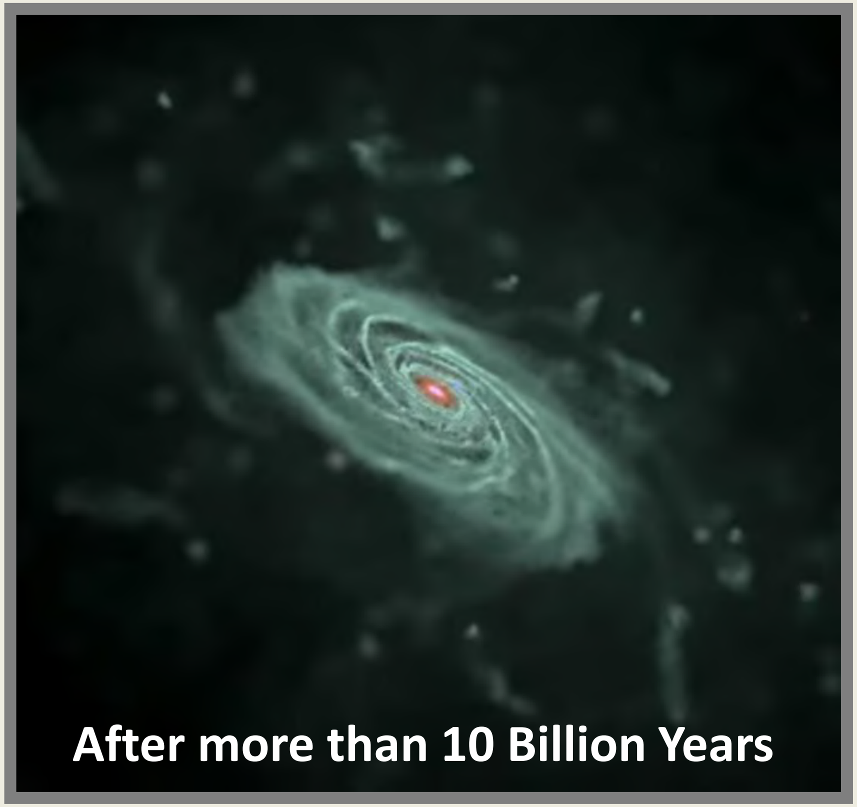


Physics Accounted For:

Fluid Dynamics, Heat Transfer, Radiation Heat Transfer, Black Holes, Dark Matter, Gas Laws, General Relativity, Magneto Hydrodynamics and more . . .

Credits: Jillian Bell ovary, Fabio Govern to; Vanderbilt University & University of Washington

What is a simulation?



Simulation

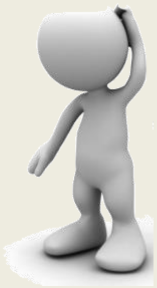
Hubble

This is what is possible with simulation . . .

Common words in die casting that I found confusing

Cold Solder?

Speed of Sound?



Uniform die temperature?

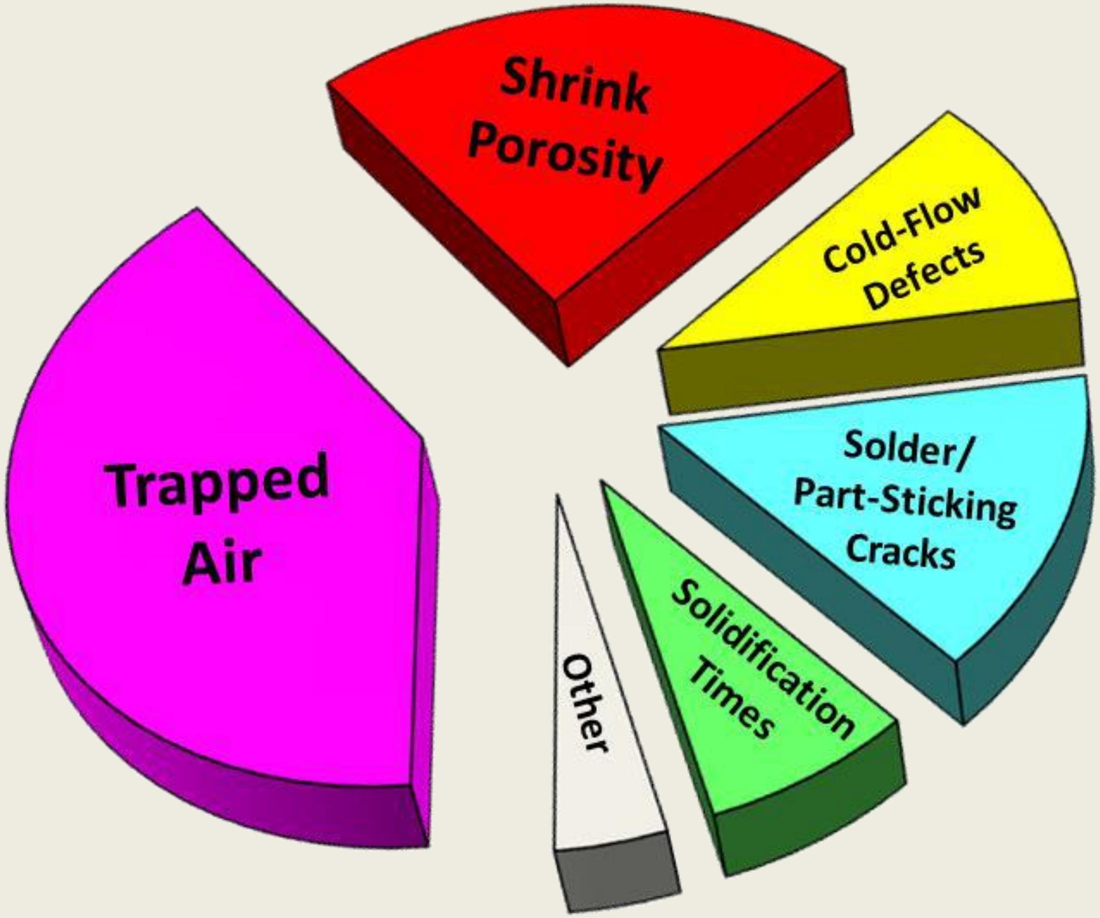
Turbulence?

Atomization?

De-Gas?

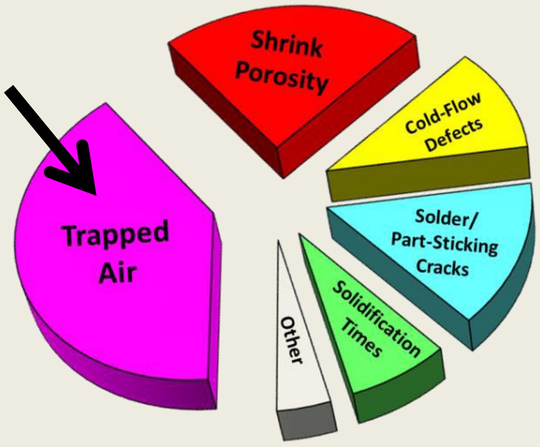
The Top Five Problems in Die Casting

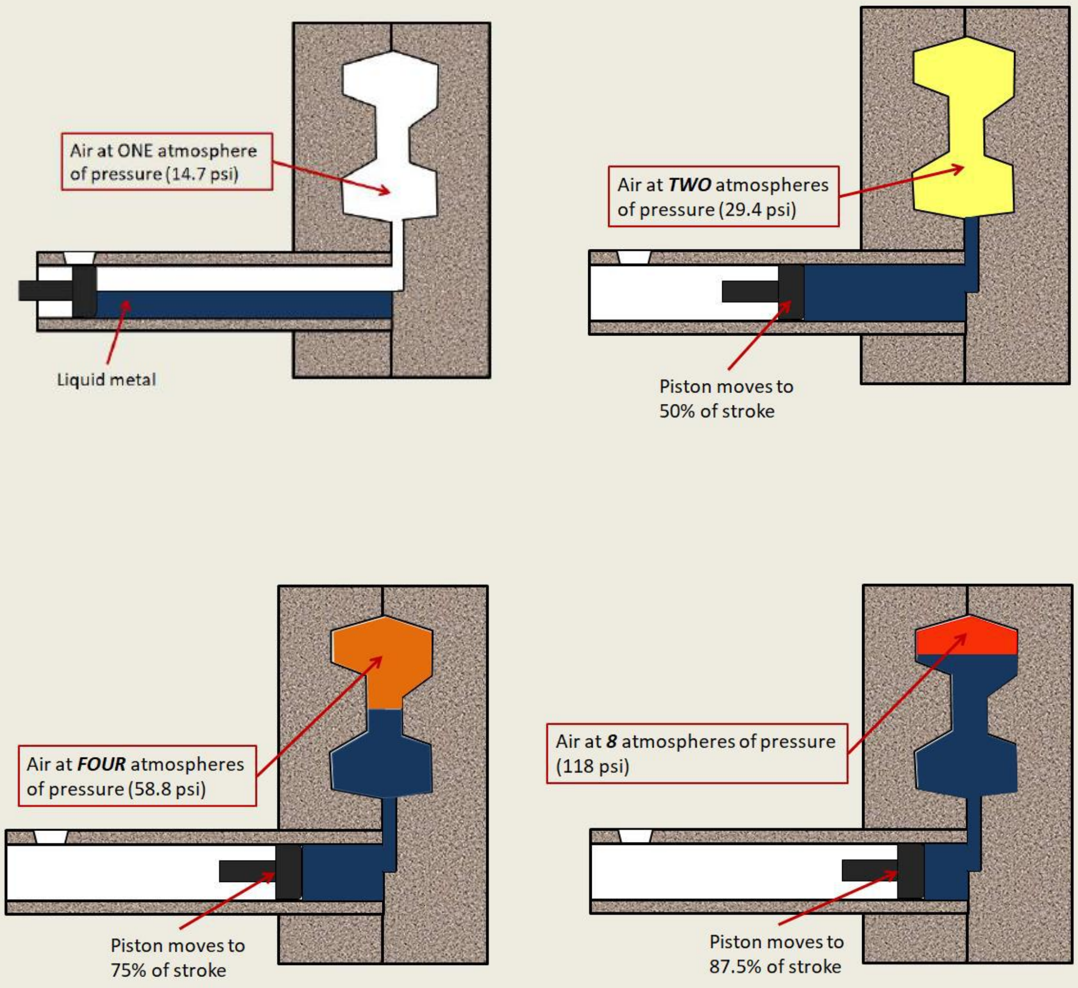
more than 90% of the time



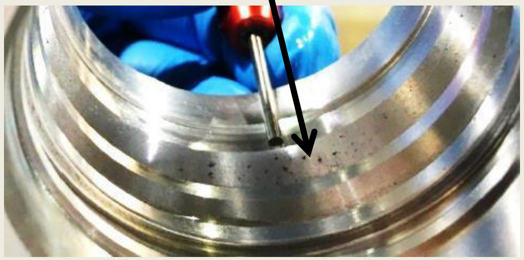
We believe that all casting processes can be distilled down to a simpler science.

Trapped Air – Gas porosity





Trapped air bubbles revealed after machining the bore of a HPDC part.



Trapped Air – Law of Gases

"Boyle's Law"

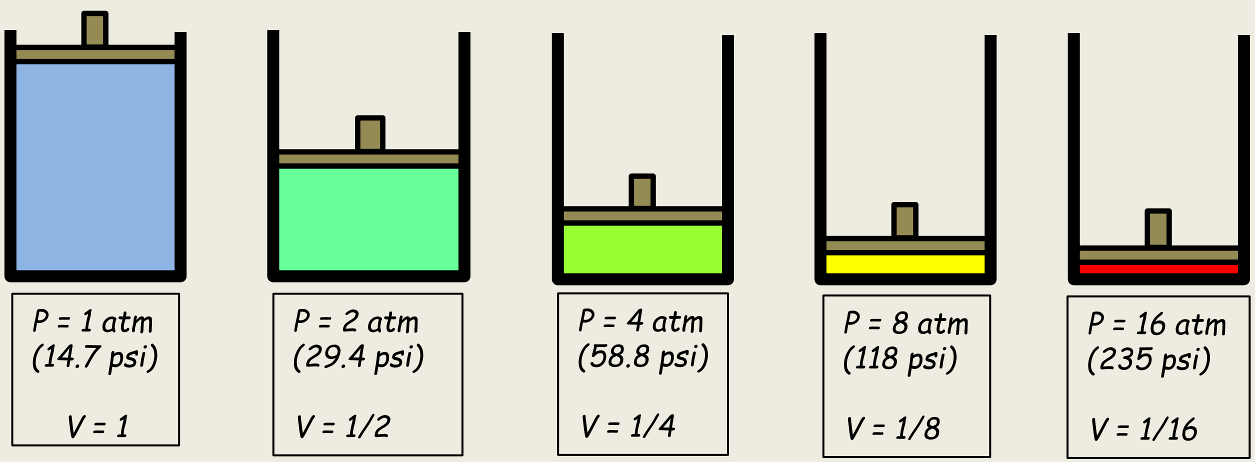
Back in the year 1662

$$P_1V_1 = P_2V_2$$

or

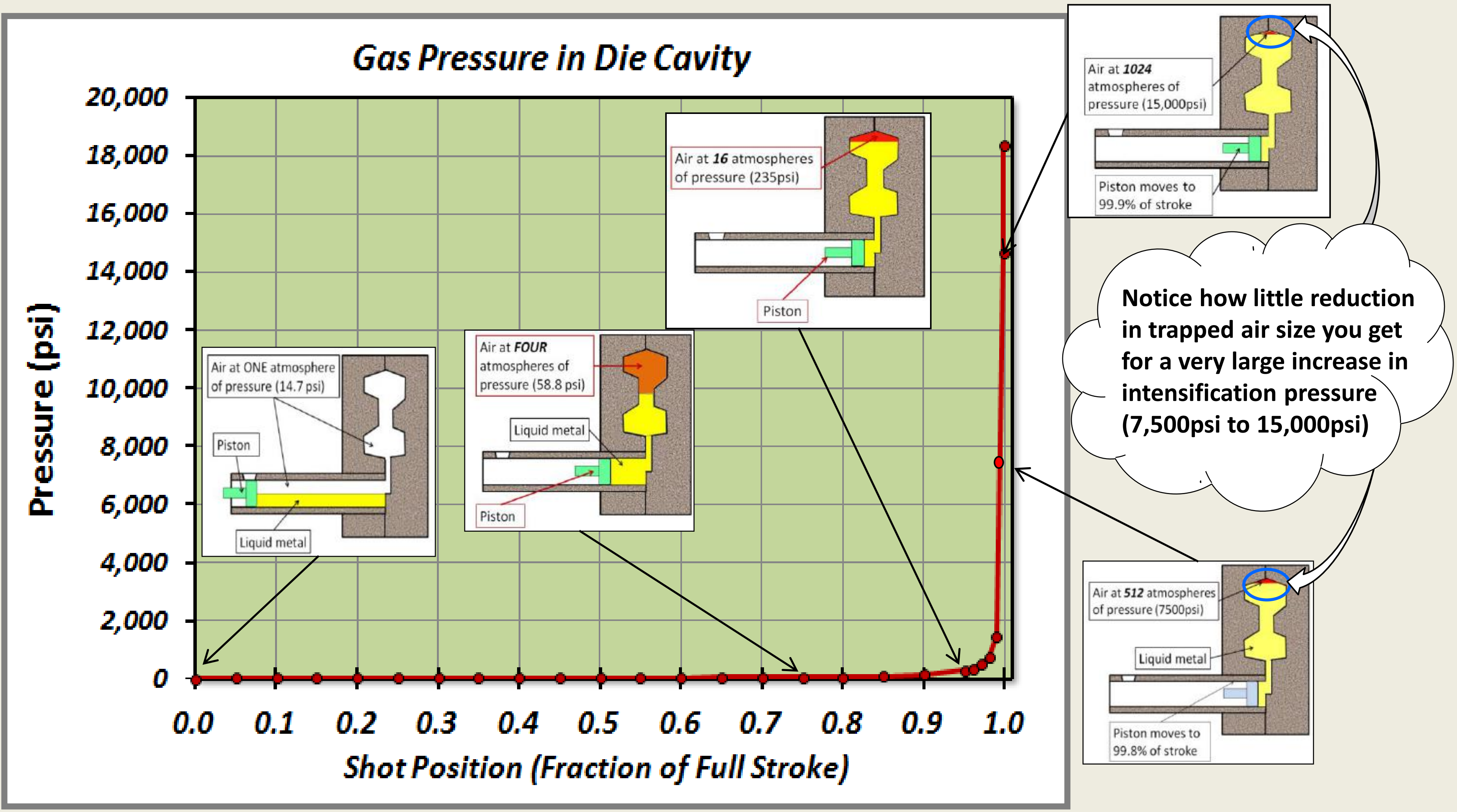
$$PV = Constant$$

Above: If you half the volume, you must double the pressure.

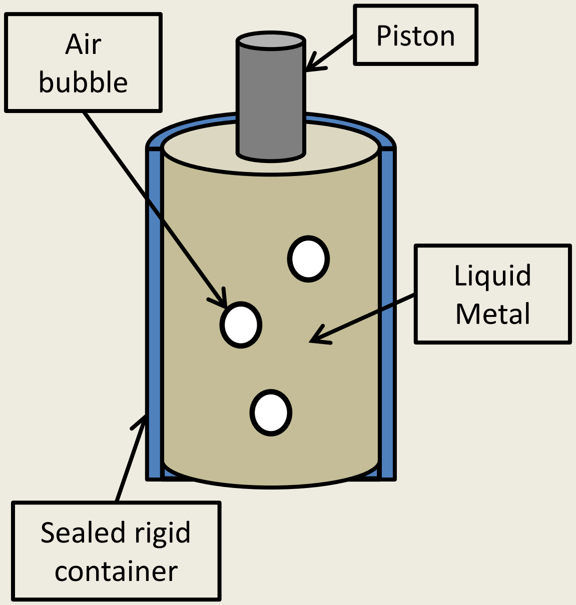


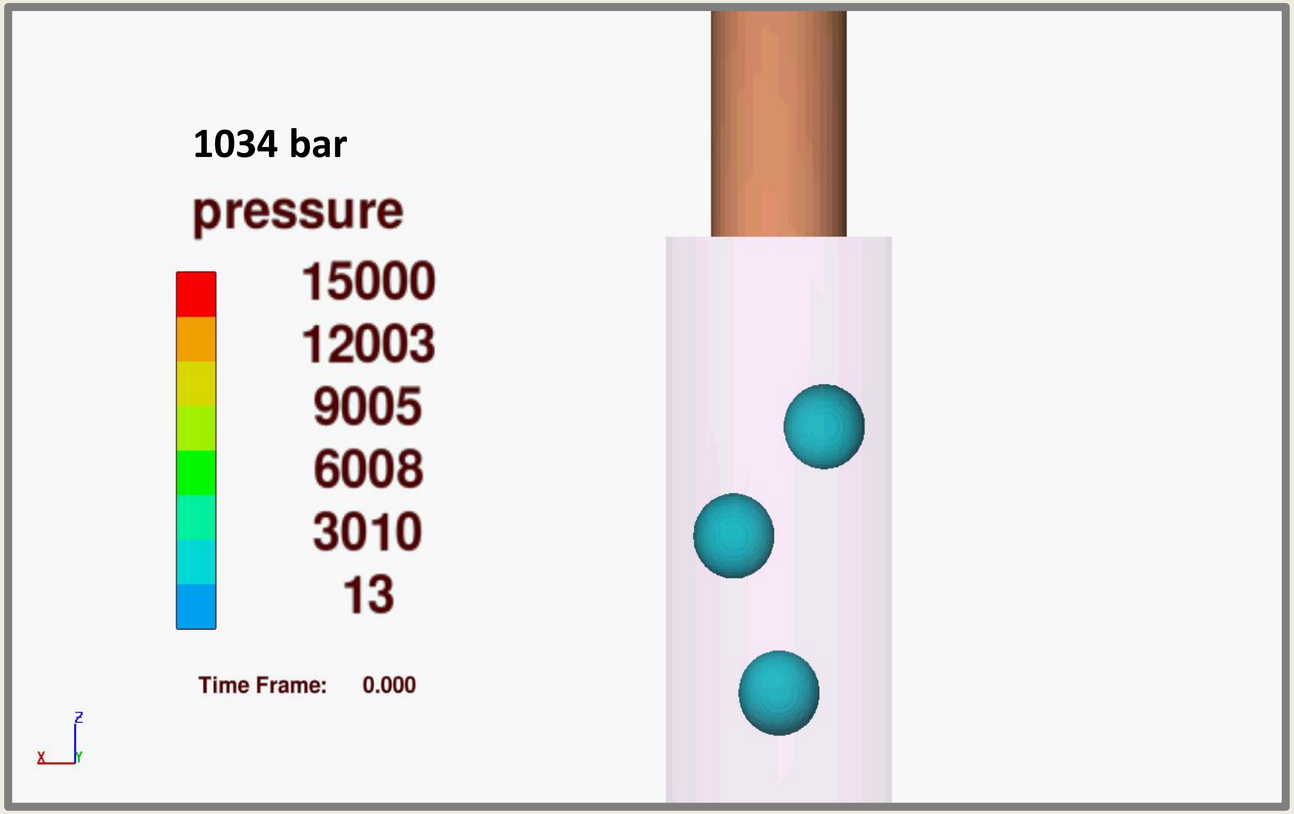
How the gas law relates to die casting . . .

The graph below shows how the trapped air pressure increase as the piston moves forward.
Note: As the pressure increased from ***7500 psi*** to ***15000 psi***, the air pocket did not get much smaller.



Simulation of air bubbles in a liquid as it gets compressed.

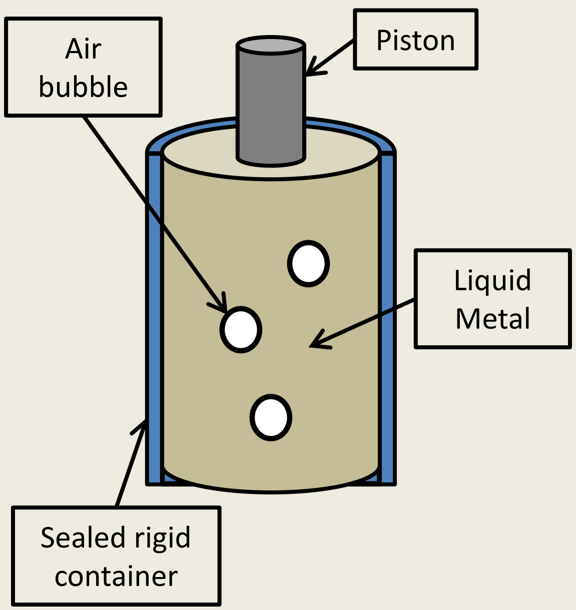


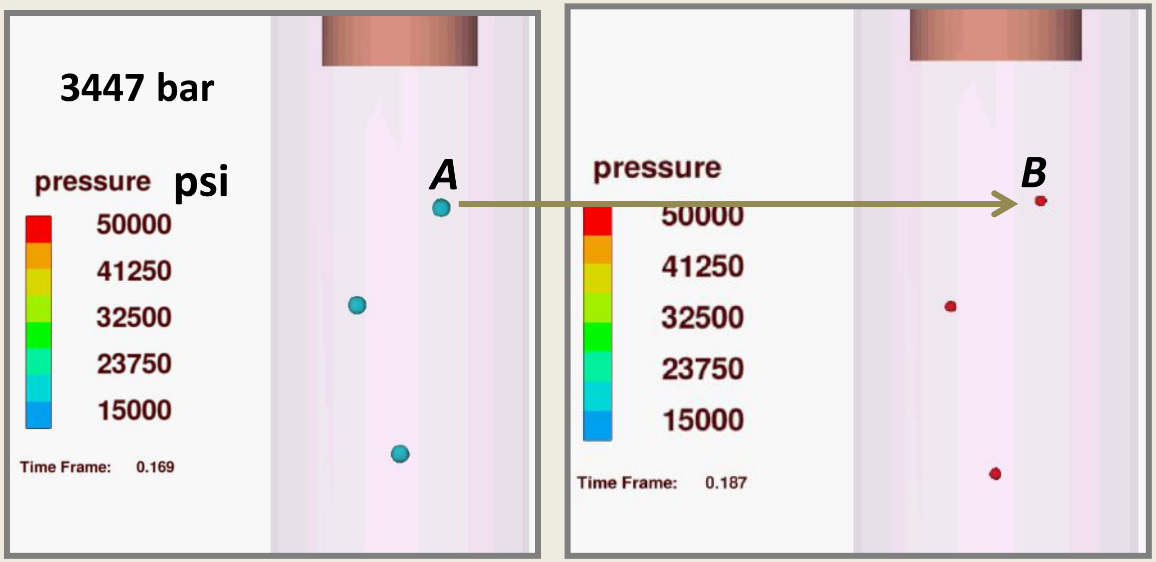


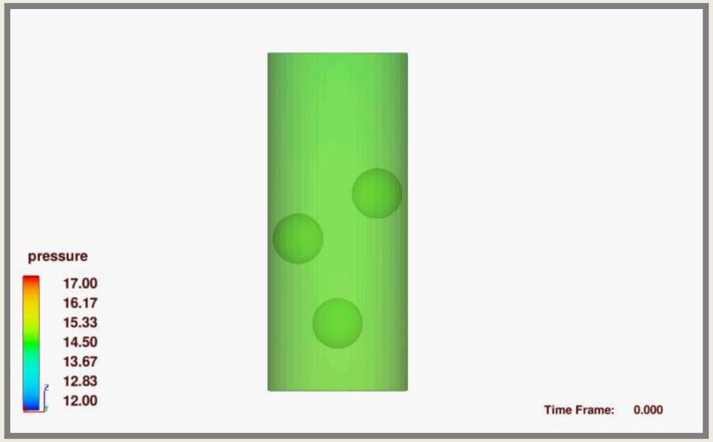
A SIMULATION

Air bubbles submerged in the liquid initially at atmospheric pressure
Then compressed as the piston invades the volume
Bubbles get smaller

Simulation of air bubbles in a liquid as it gets compressed.







To decrease the bubbles "A" to "B", you need 50,000 psi of Intensification.

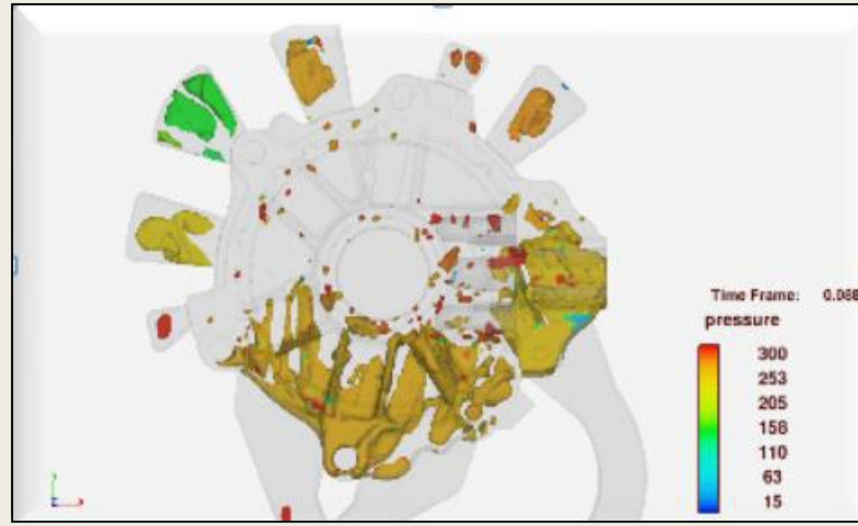
Some Take Away From Our Review of The Gas Law

Porosity the size of the head of a nail requires a baseball size volume of air.

How this awareness helped us to understand and solve gas porosity:

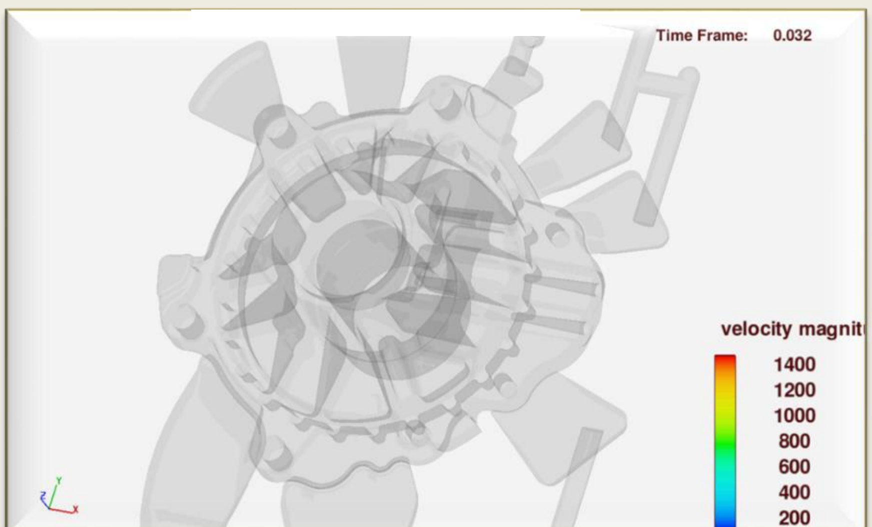
- *Know that gas porosity seen in X-Ray is a lot of air pushed to that location*
- *Helps to understand what it takes to resolve trapped air concerns in die casting – eg. Smoothing out a runner won't do the trick!*
- *Interpret simulations*
- *Helps us to focus on what really maters and ignore that which is negligible.*

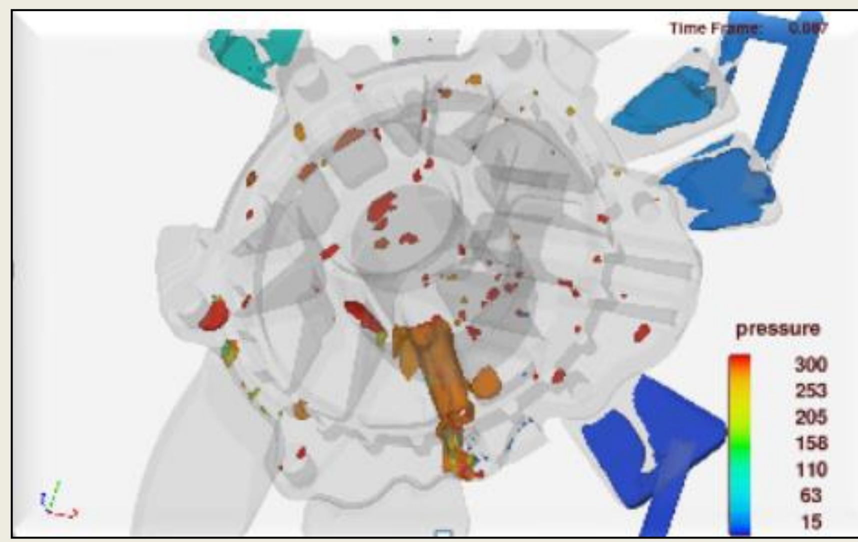
Example of the value of this approach . . . Simulation Interpretation



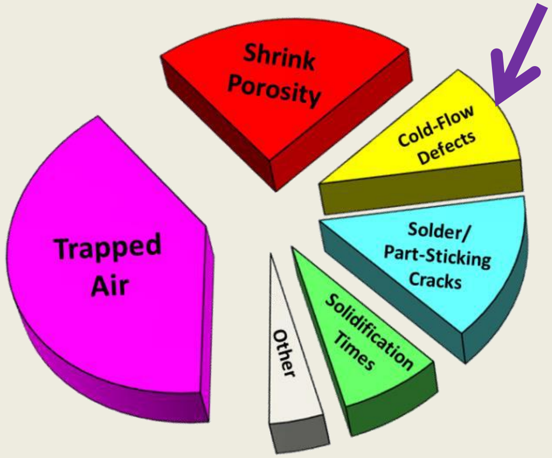
Typical Flow Simulation

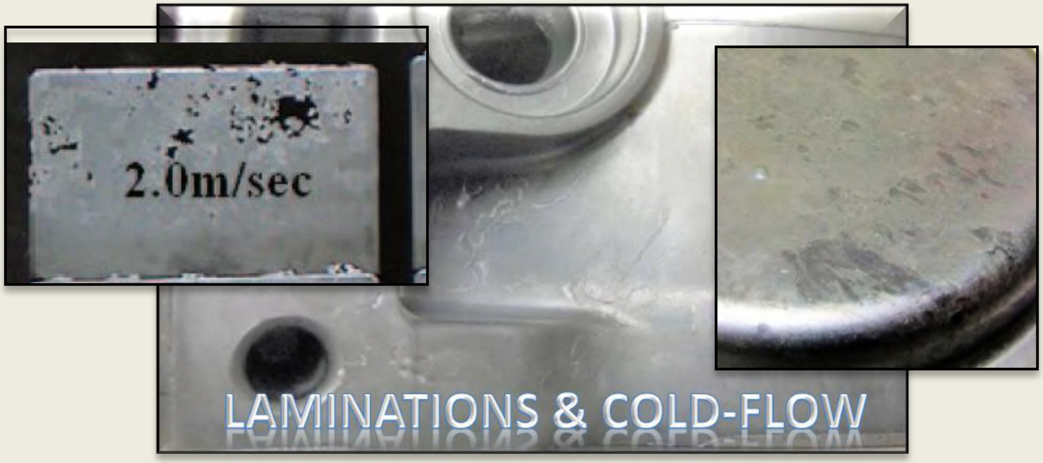
Actual air Trapped In Cavity



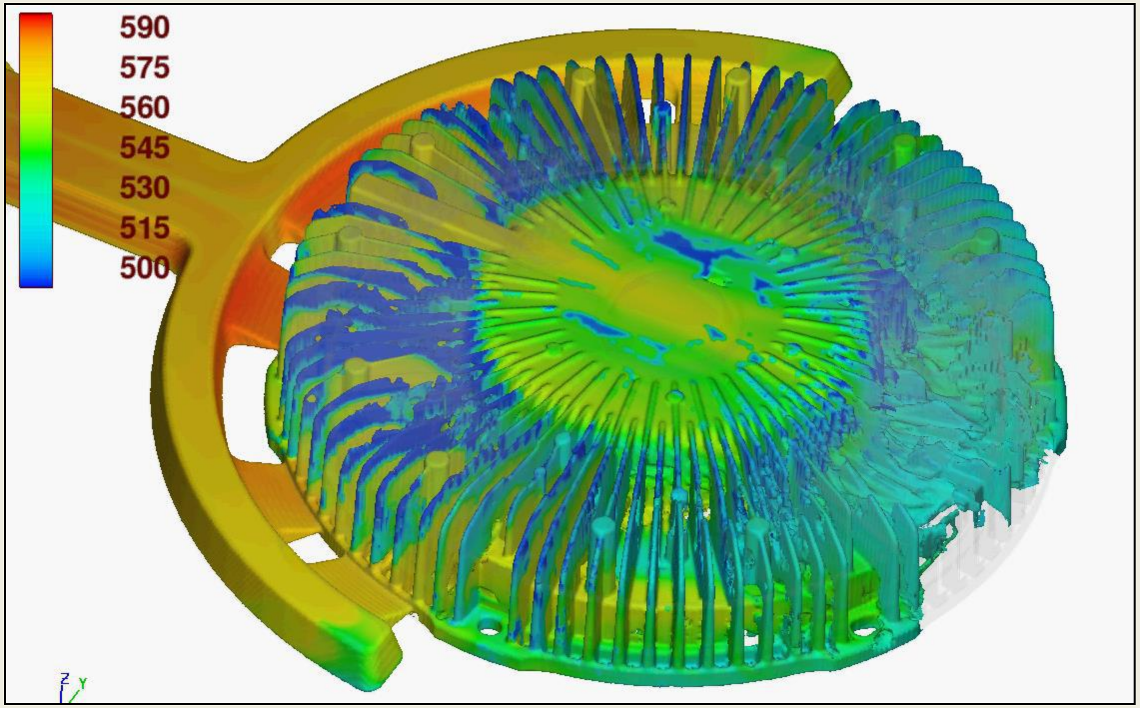


Can We Predict Cold Flow Defects?

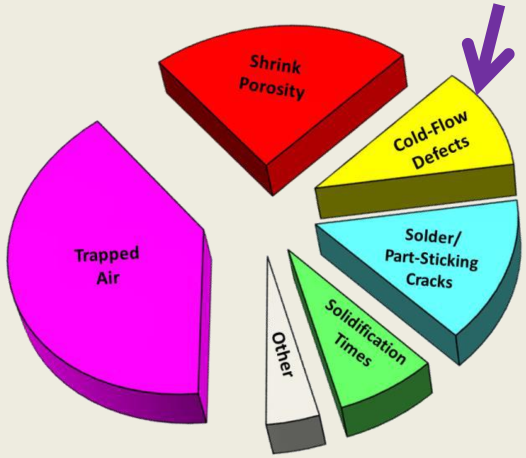


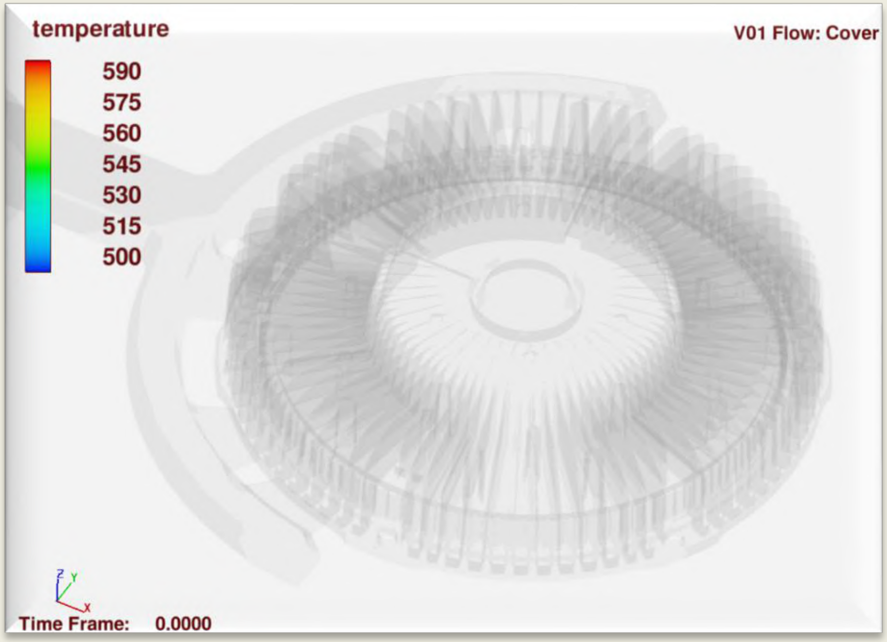


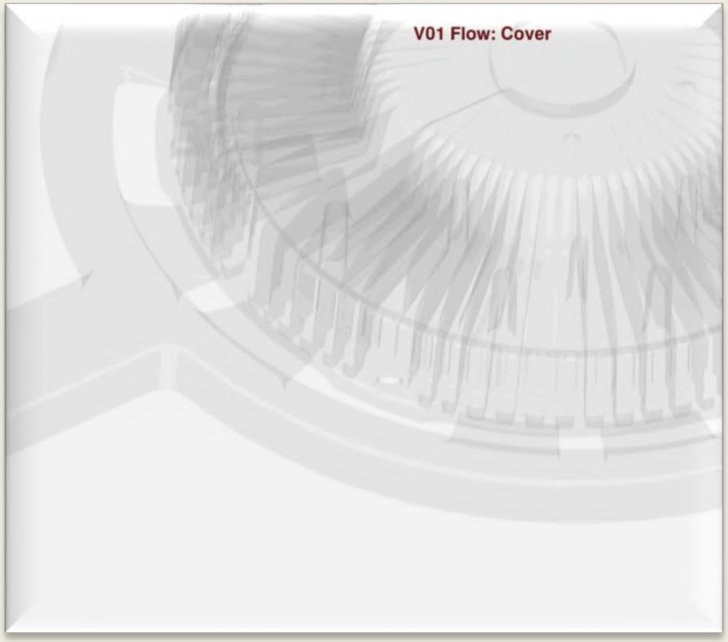
- *It is now possible to directly predict when the metal freezes during filling*
- *This empowers us to know ahead of time if a part can be successfully cast in a given machine*
- *We now can specify on "paper" exactly what is required to successfully cast a given ultra thin part* ***– without building a single thing!***



Simulation Explicitly Predicts Cold Flow Defects



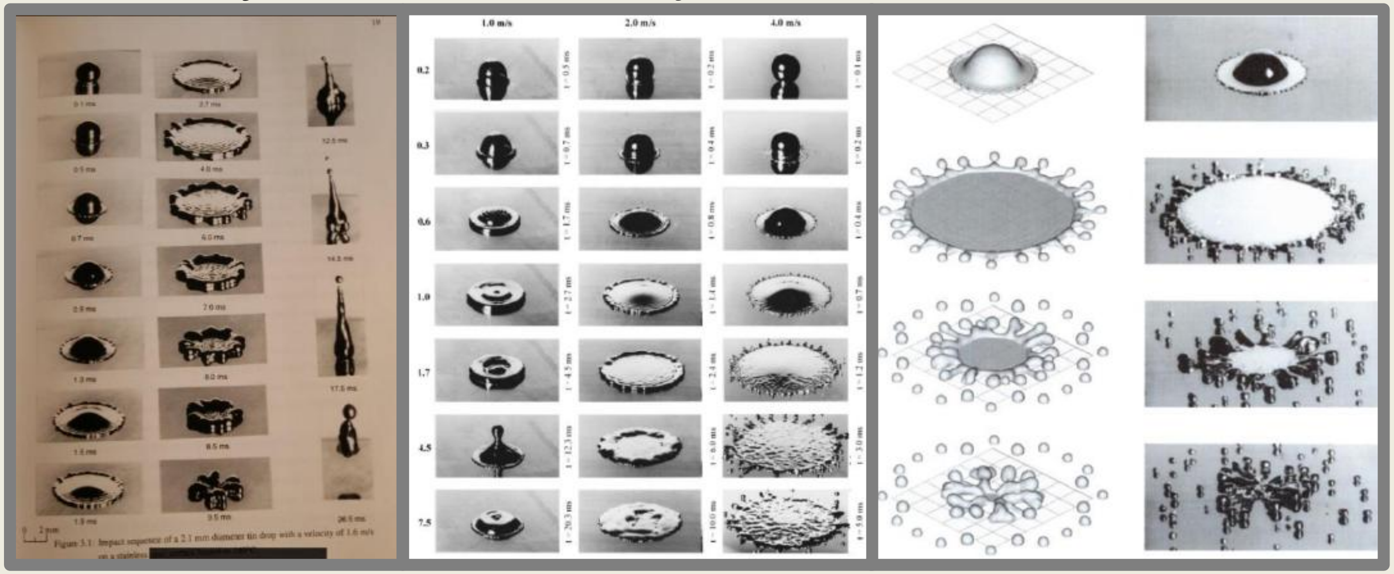


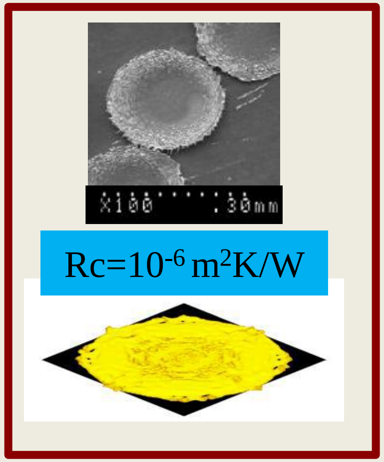


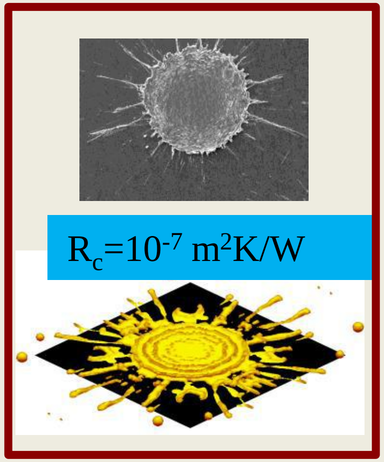
Cold Flow Defects

Some of our research collaboration at U of Toronto.

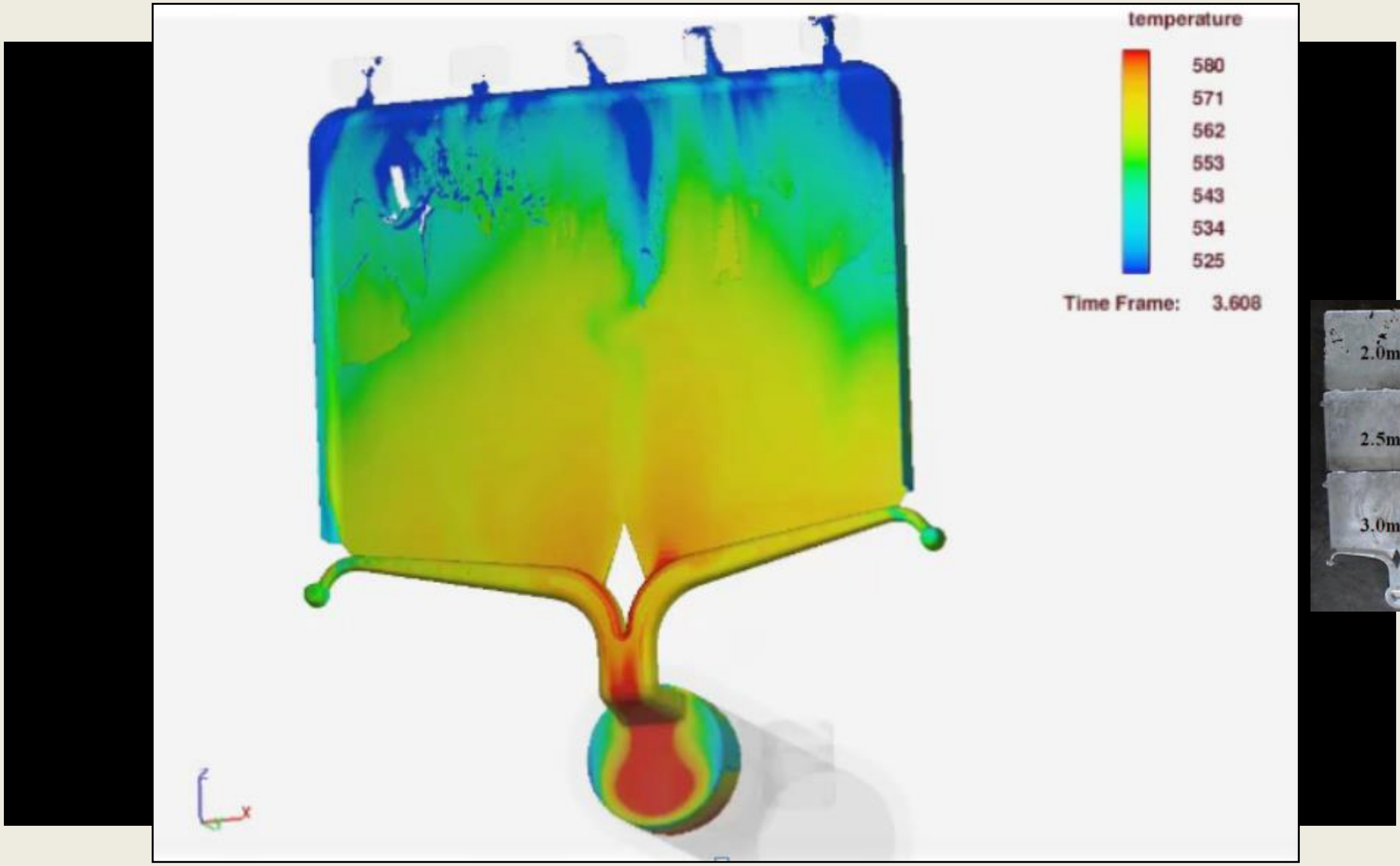
Hot surface *Cold surface* *Simulation* *Reality*

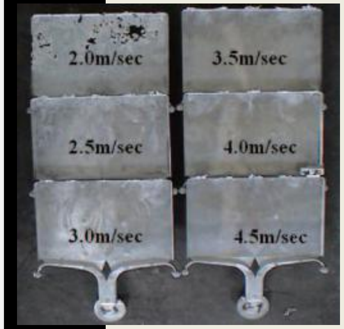






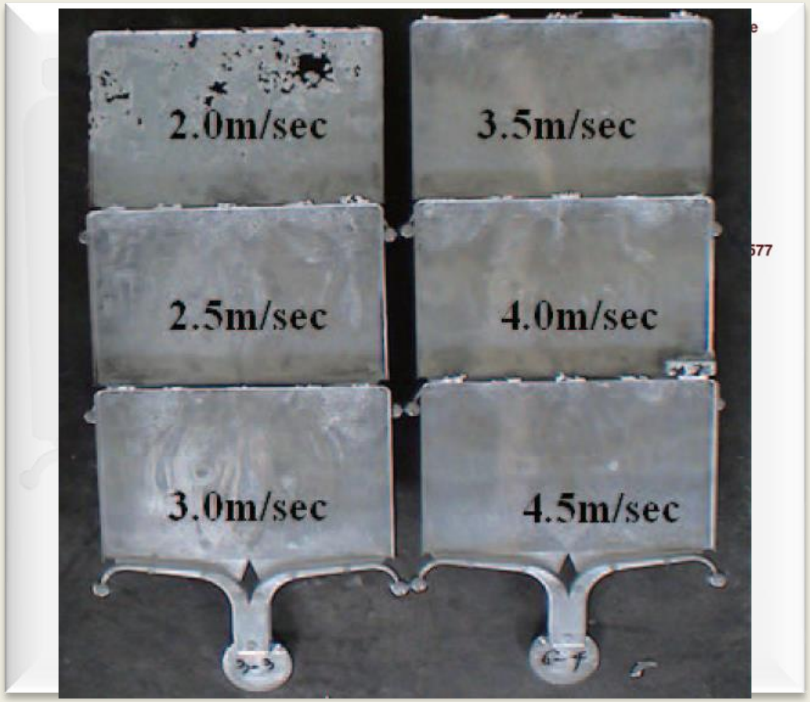
Freezing During Filling - HPDC

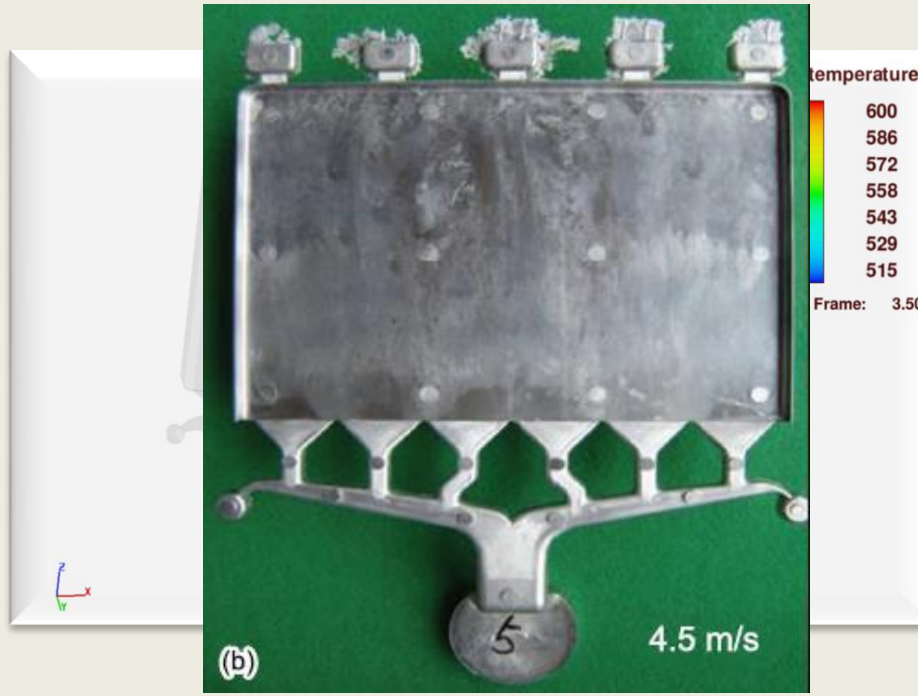




Simulation accurately predicted cold flow defects when die caster attempted to cast a 0.8mm thick laptop cover out of A383.

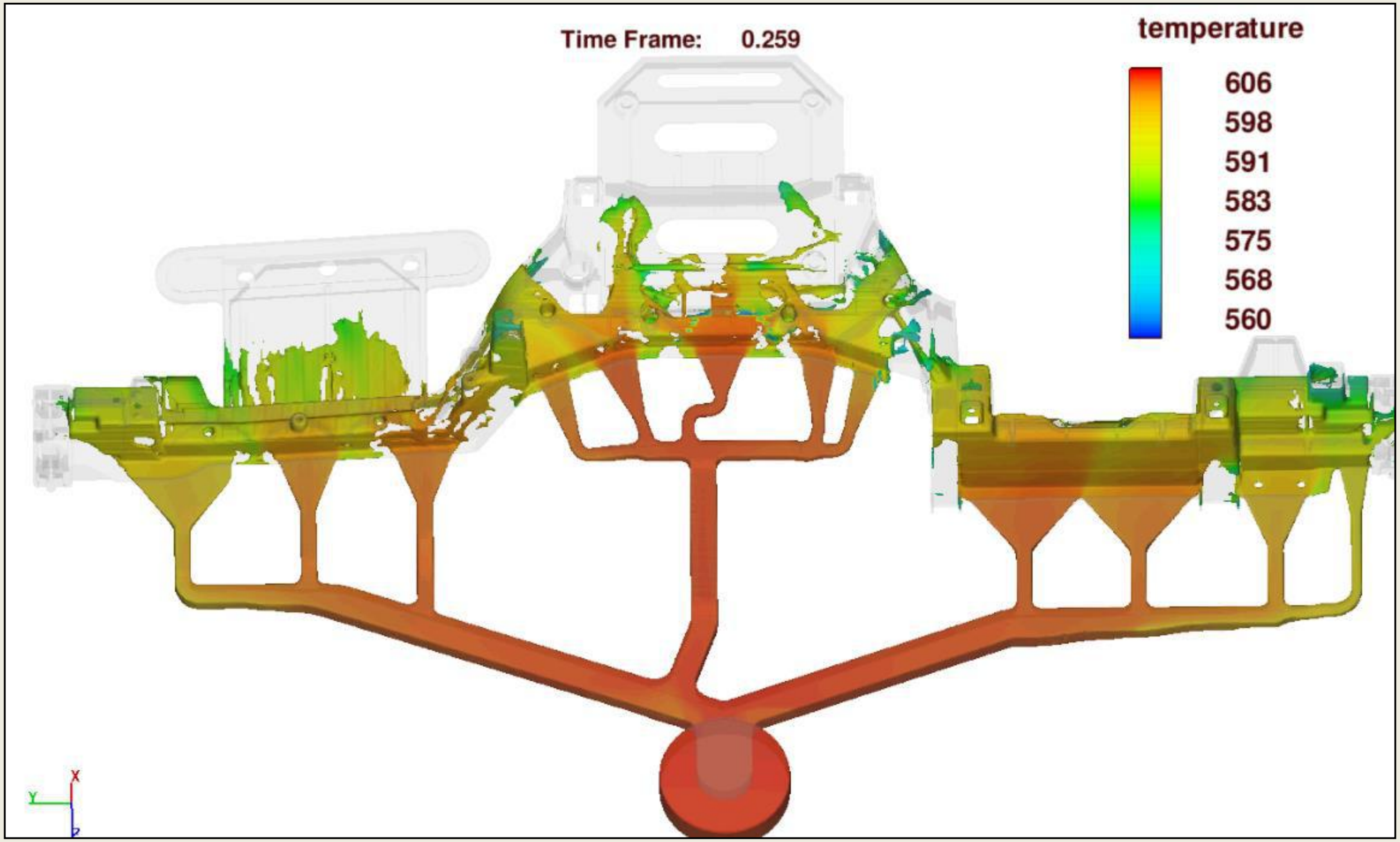
Freezing During Filling - HPDC





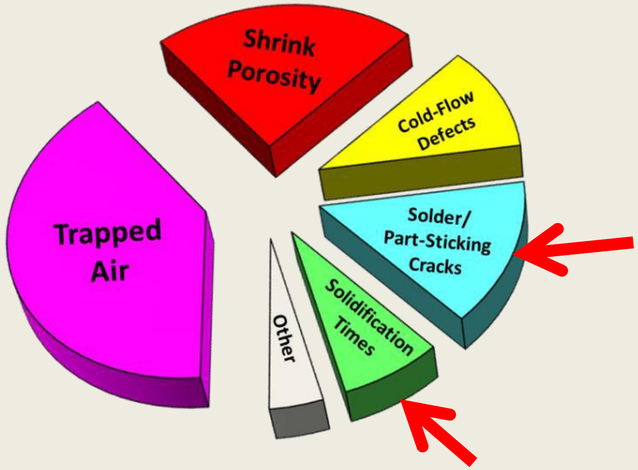
Simulation accurately predicted cold flow defects when die caster attempted to cast a 0.8mm thick laptop cover out of A383.

Large Structural Automotive Parts

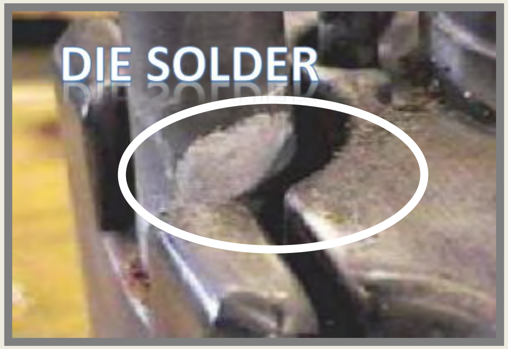


We now can specify on "paper" exactly what is required to successfully cast a given ultra thin part ***– without building a single thing!***

Die Cooling and Cycle Time



Modes of failure when we run faster:



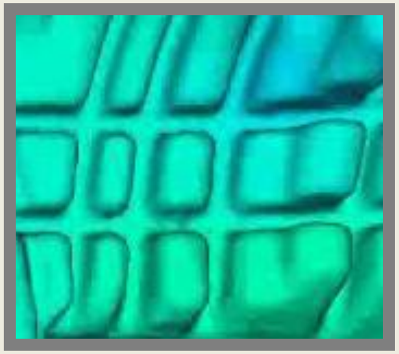
PART STICKING

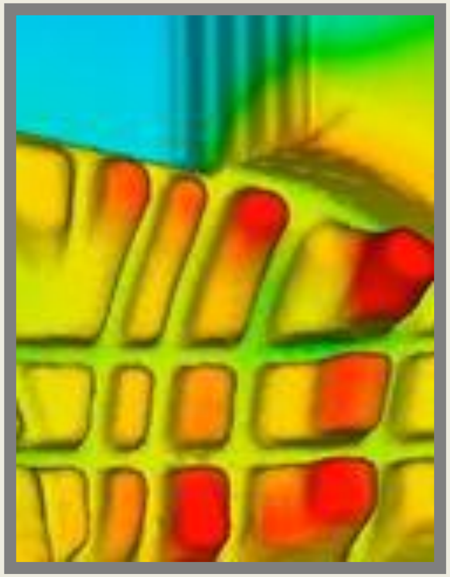
INCOMPLETE SOLIDIFICATION

EXPLODING BISCUITS

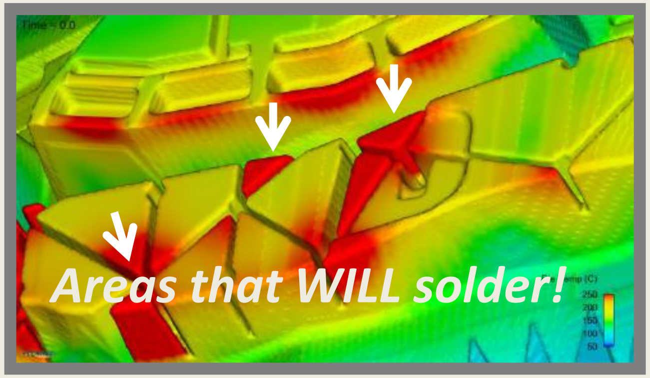
It is possible to calibrate simulations to predict die solder under different conditions (e.g.: Micro spray, oil cooling, water cooling, different metal temperatures, different cooling methods, etc.).

Die Cooling and Cycle Time – Die Solder

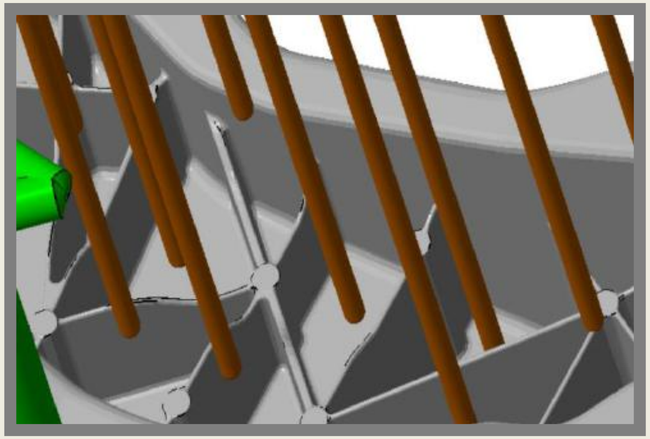


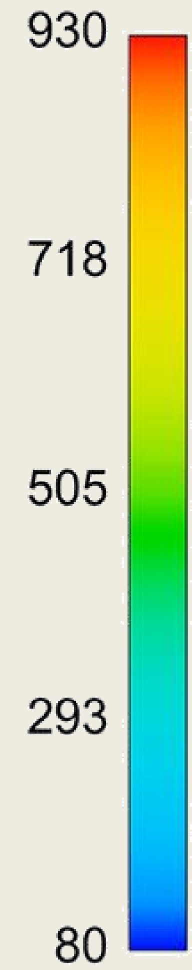


Heavy powertrain part: Conventional cooling technique was maximized. Needed to review other methods of cooling.



Thin walled structural auto part with "micro-spray" requires careful attention if we wish to run steady.



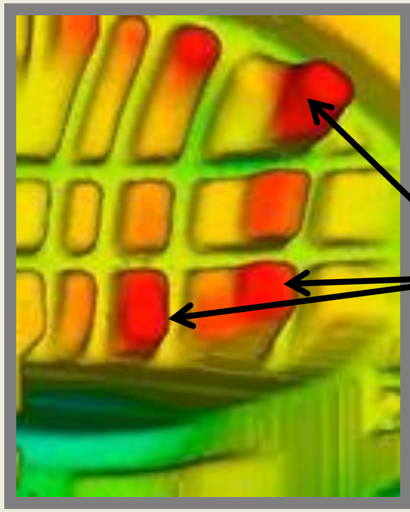


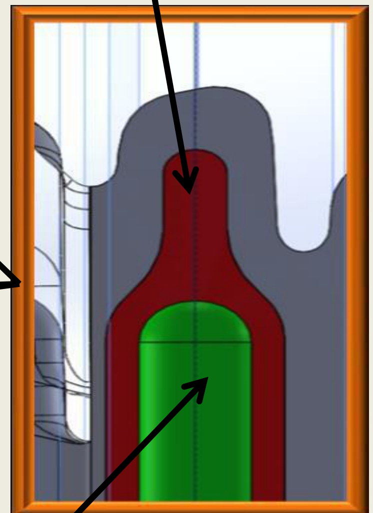
*** Rule of Thumb: Solder happens when the die cavity peak temperature exceeds approximately 1004°F (540°C) During Dwell.*

Cycle-time

COPPER

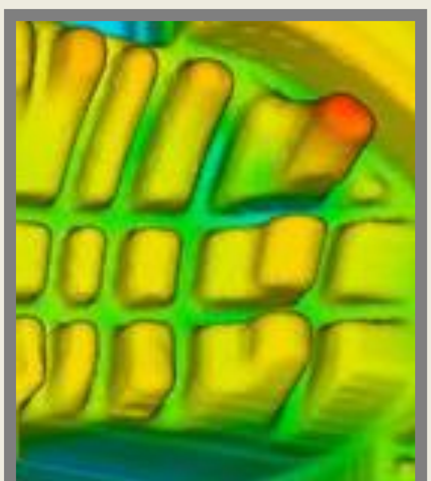
BEFORE





Water Flow

AFTER

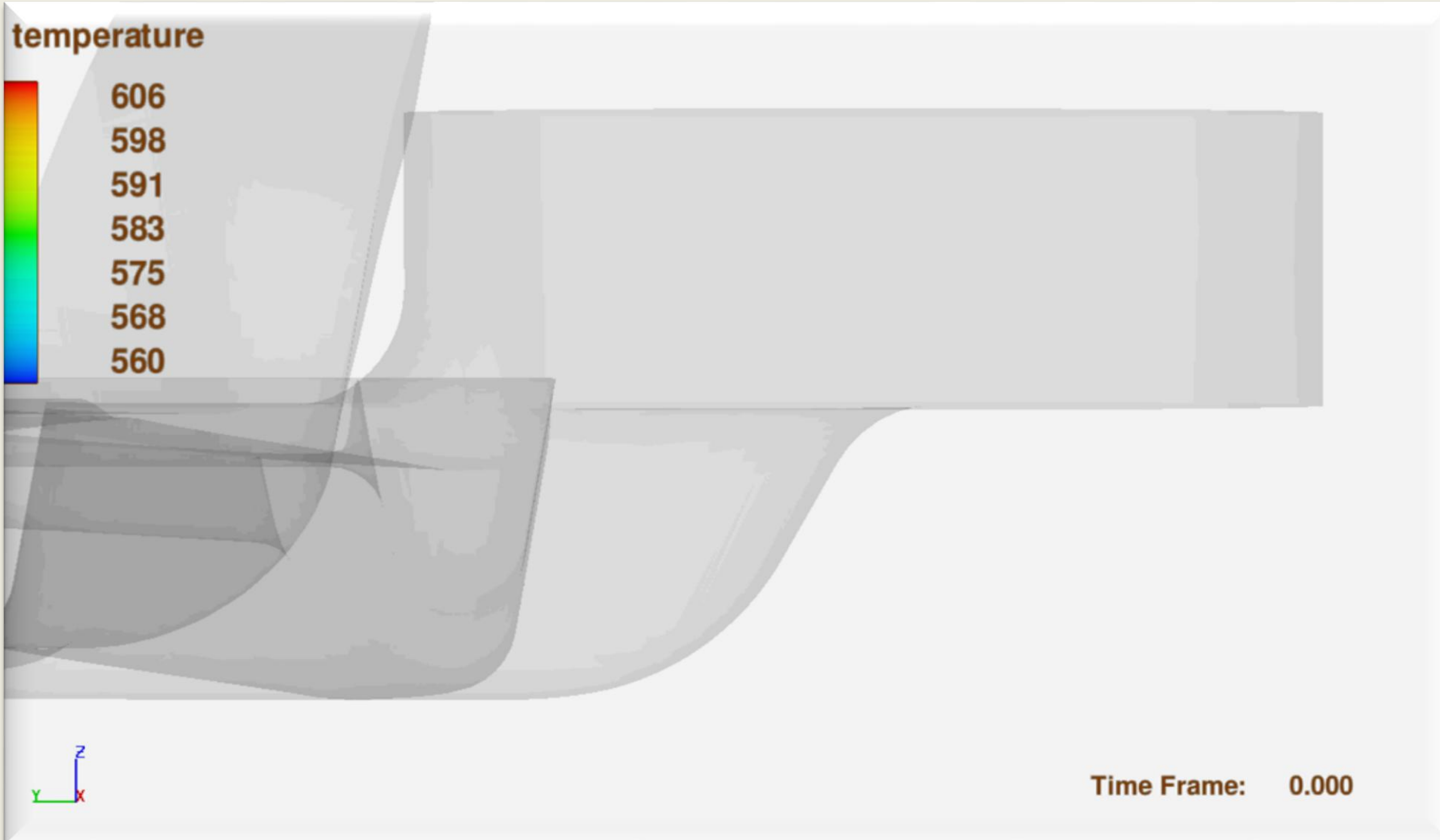


Below: Die overcooled in some areas, we can specify precisely temperature settings for heating and cooling lines that make a good part.

RESULT

- *This copper inserts that we proposed eliminated die solder and is not a risk for water leaks – Less than 1% scrap after ~500 parts (not including start up scrap).*
- *It is possible to explicitly predict die solder on new programs*
- *We can test any cooling method and trust the simulation prediction for die solder*
- *And from our "cold-flow" prediction, we can tell what die temperature is required to make a good thin-walled structural part*

Biscuit Solidification Times

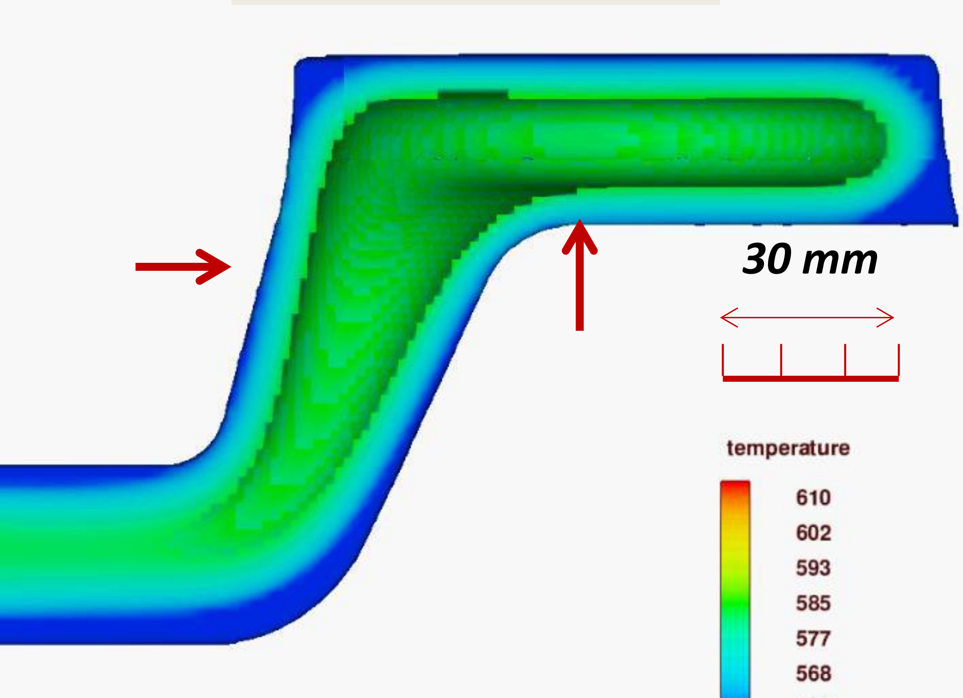


Biscuit Solidification

Baseline at 15.0 sec shows the same solidification as the aggressive cooling at 11.0s.

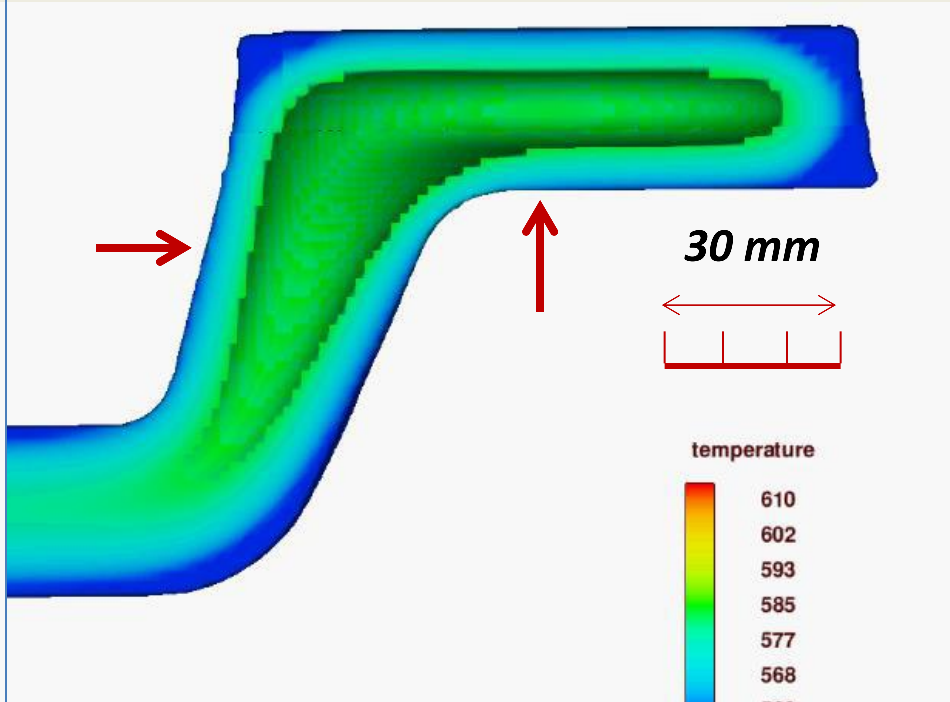
We can eject the part after 11.0 s of dwell for aggressive cooling.

Conformal Cooling



Solid layer formed after 11.0 sec

Conventional Cooling



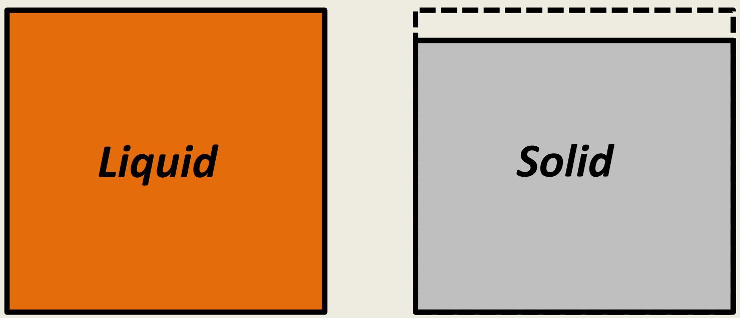
Solid layer formed after 15 sec

HPDC: Shrinkage in Die Casting . . .

Shrink porosity in castings is well understood and most of us know its mechanism quite well. This is just a recap on how shrink happens (in general) and specifically how shrink porosity form in die casting. We will then review measures that can be taken to reduce shrink in die castings and assess their effectiveness.

The fundamentals:

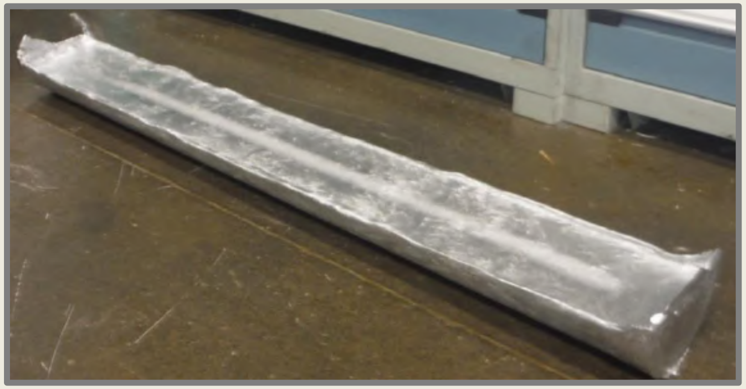
Most metals and alloys are denser as a solid, and become less dense in their liquid state. ***So as liquid metal solidifies, it must occupy less space***:

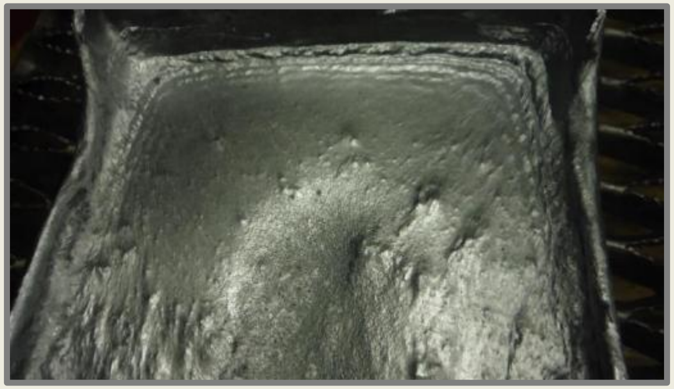


As the liquid metal changes to a solid, it MUST occupy a smaller volume. This guarantees that shrink will happen every casting!

**** Later we will see how we can reduce this shrink.***

HPDC: Example of Shrink Formation





Above: *Molten aluminum poured into a shot sleeve and left to solidify. As the log solidified, the top surface sinks due to shrinkage. – 40lb shot.*

Notice how large a void is formed just from shrinkage!

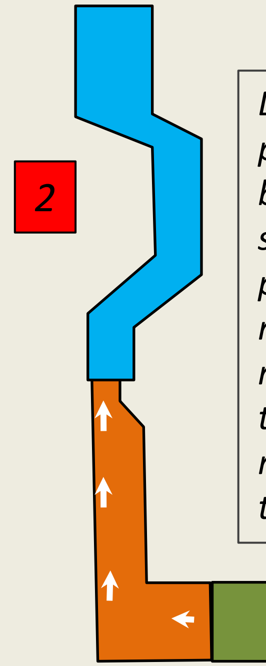
For this 40lb pour weight, the aluminum (A380) will shrink 9% and this translates to 41 Cubic Inches.

The volume of one tennis ball is only 8 cubic inch!

Therefore the molten aluminum shrunk by Five Tennis Balls!

So, how come we don't see shrink in castings nearing tennis ball sizes?

HPDC: Why is it that we don't see five tennis balls of shrink in a casting?



During solidification, the plunger pushes metal into the biscuit and runner and feeds shrink. This is why you have porosity free biscuit and runners. And the runner/biscuit is about 40% of the total shot weight. This removes about another two tennis balls.

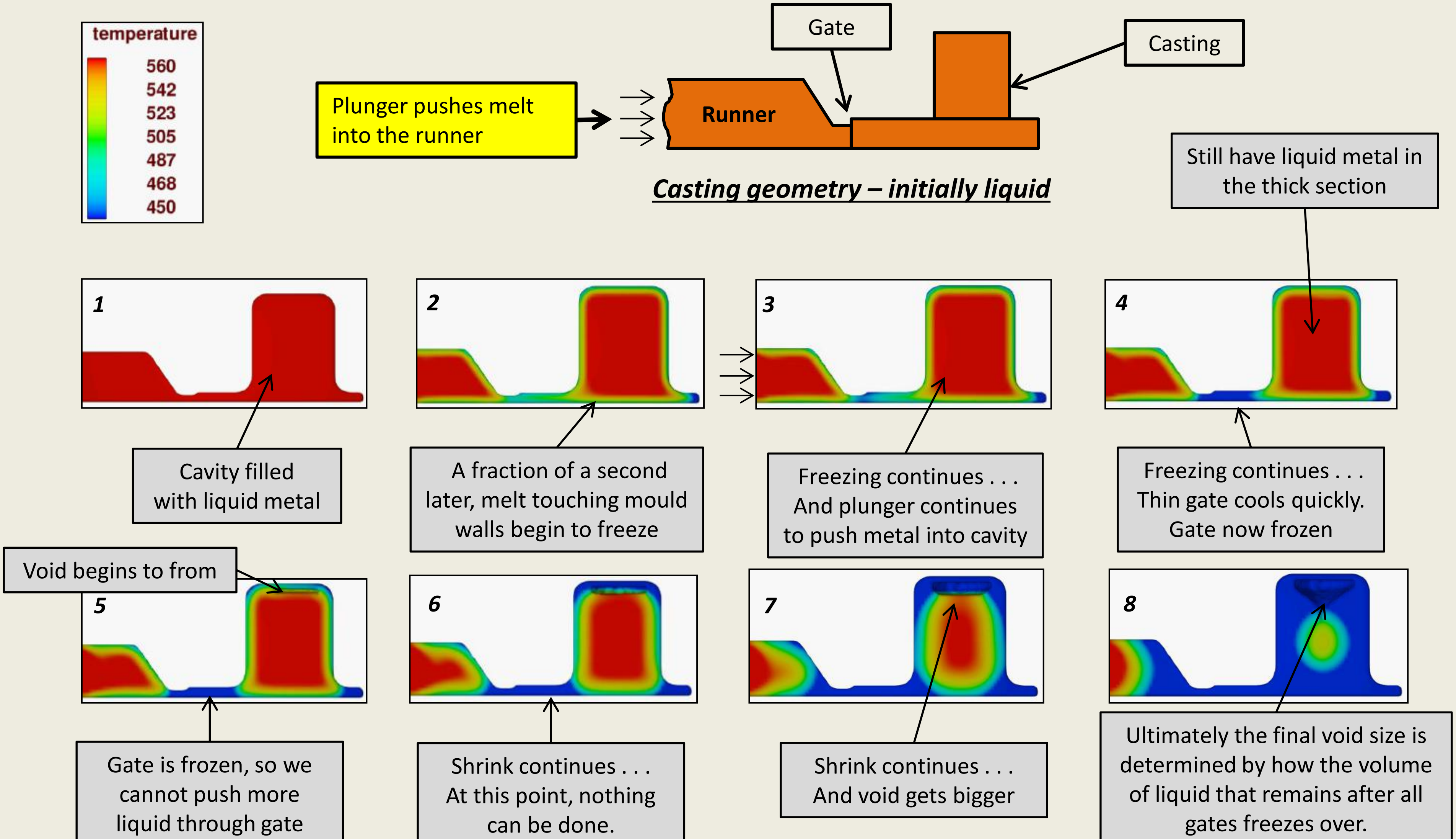
Though this is not confirmed, but there is shrinkage that is evenly distributed around the part and is not easily detectable – micro porosity??

3

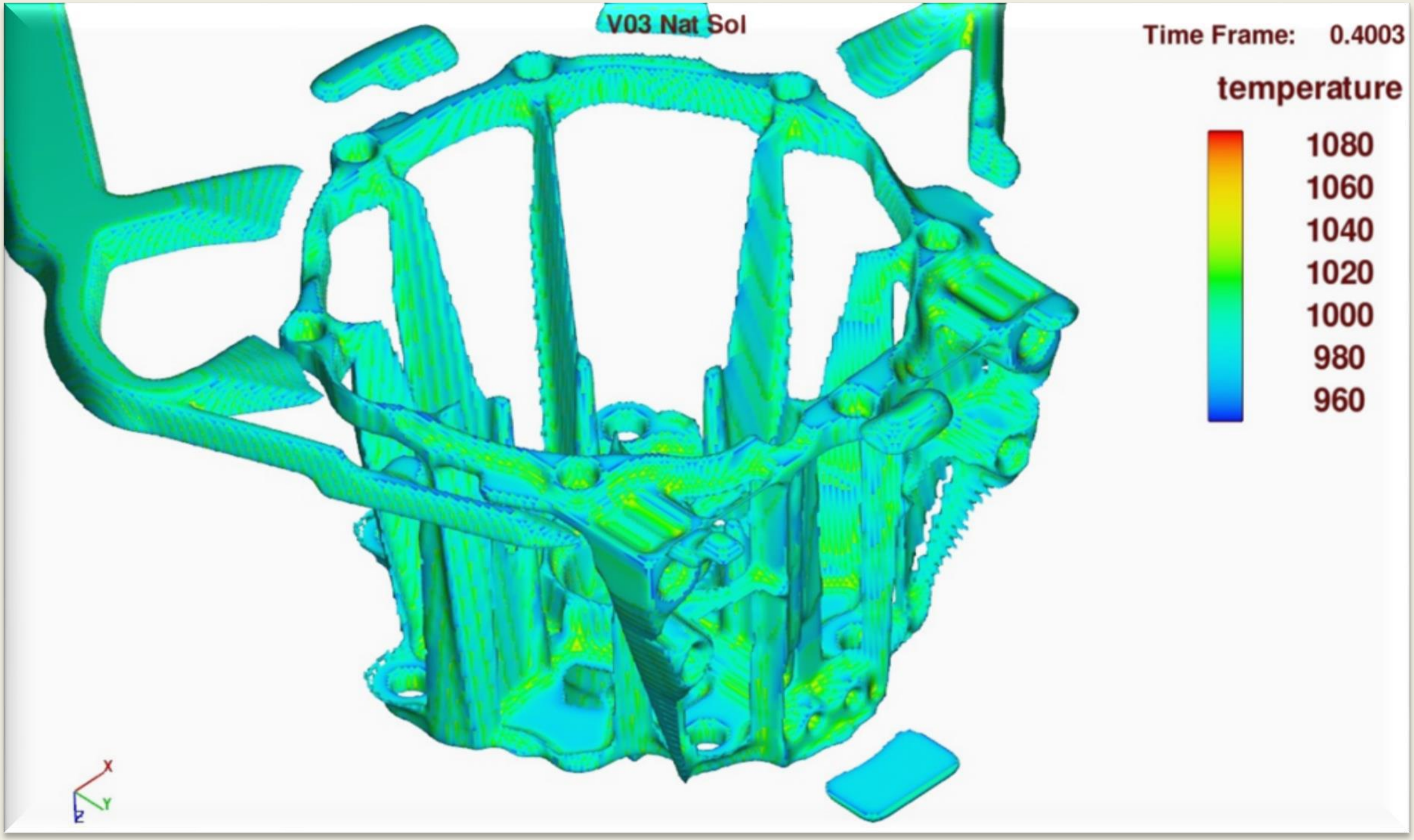
From this simple illustration, we can see that shrink porosity that ends up in the part is largely determined by how much time you have to pump metal through the gate during solidification.

HPDC: A closer look at feeding shrink . . .

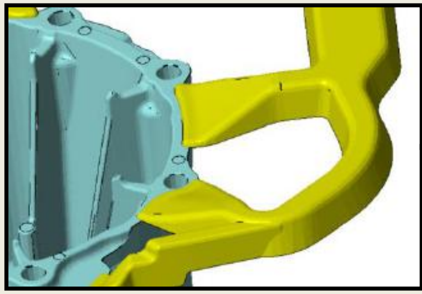
Below is a simple example that can help to understand how shrink is formed in die casting:



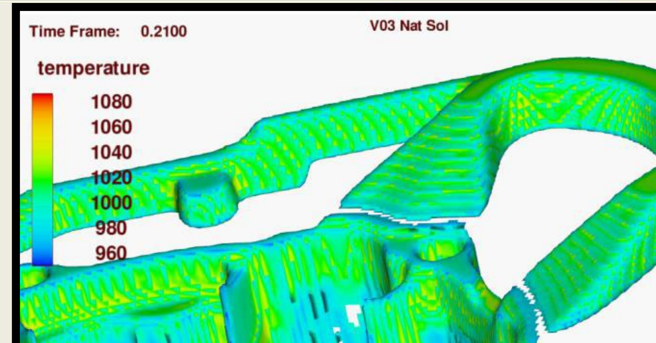
Gate Freeze Time



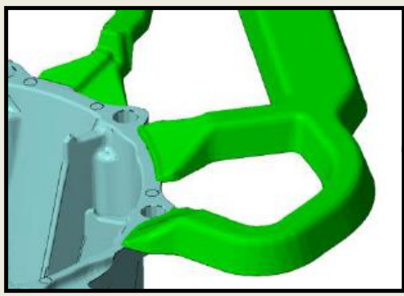
Results: Gate Freeze Time



Original Gate 3.0 mm

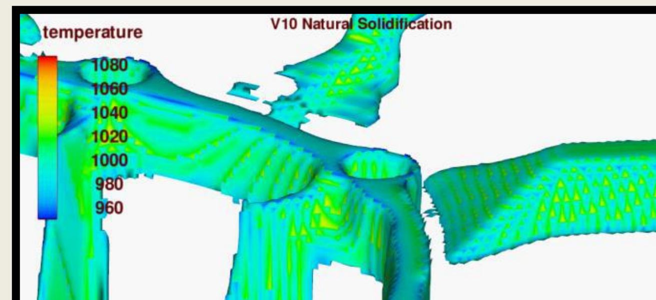


Gate Freeze Time = 0.210 seconds

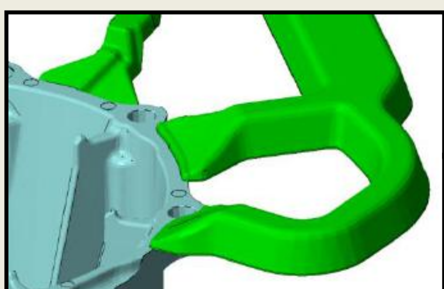


Original Gate with Steeper Ramp - 3.0 mm

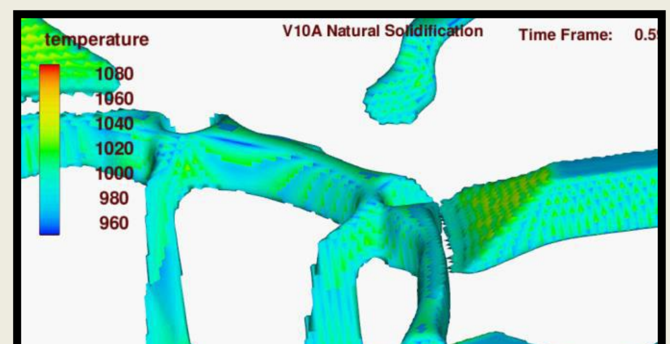
Note: Just adding a ramp increased the freezing time by 70 ms



Gate Freeze Time = 0.280 seconds



Original Gate with Steeper Ramp & 3.8 mm



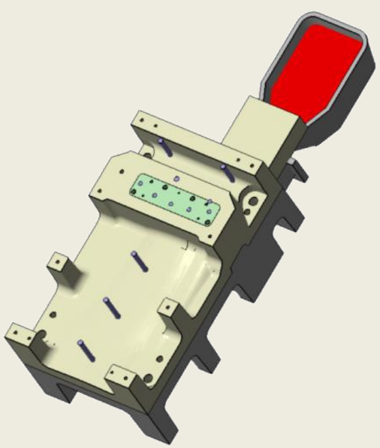
Gate Freeze Time = 0.500 seconds

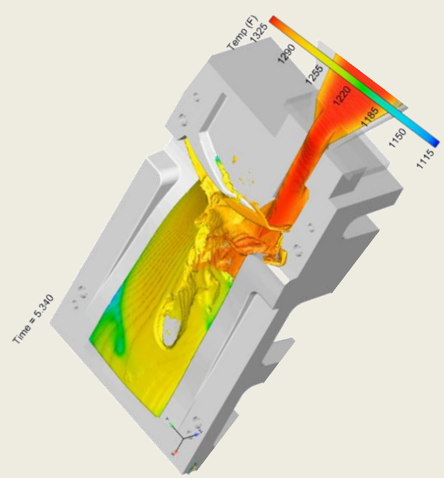
The Goal of Any Casting Process

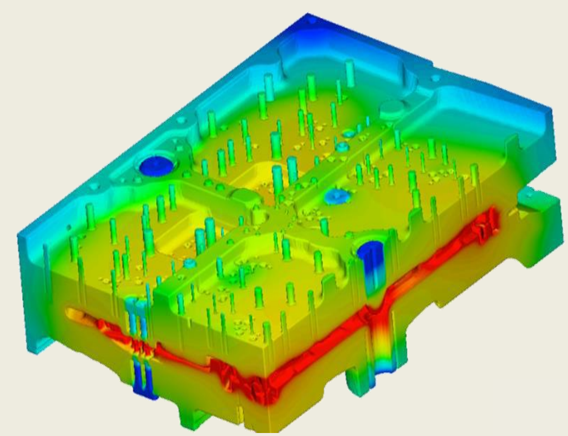
1. Fill mold before material freezes
2. Keep track of the where the air ends up and vent it
3. Let solidify … Feed shrink: Path to add more liquid . . .

The Physics that captures the above stages remain the same regardless of the casting process.

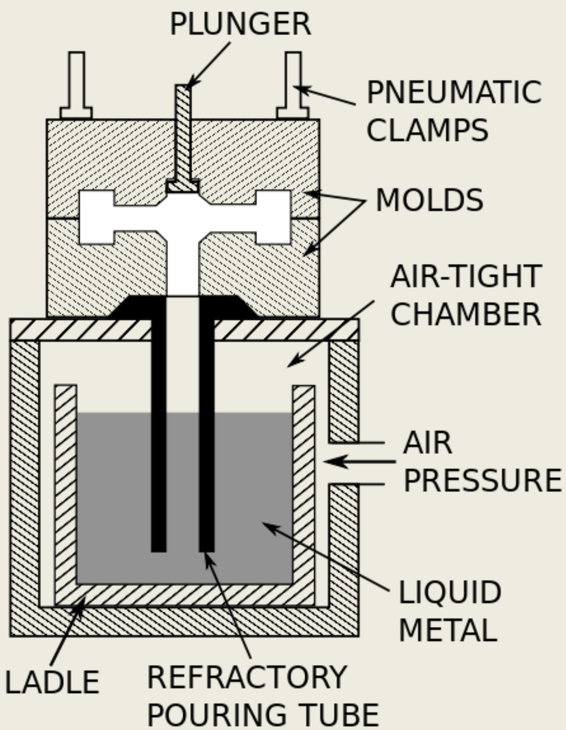
Gravity | **Air Back Pressure** | **Vent Discharge Coefficient** | **Heat Loss During Filling**

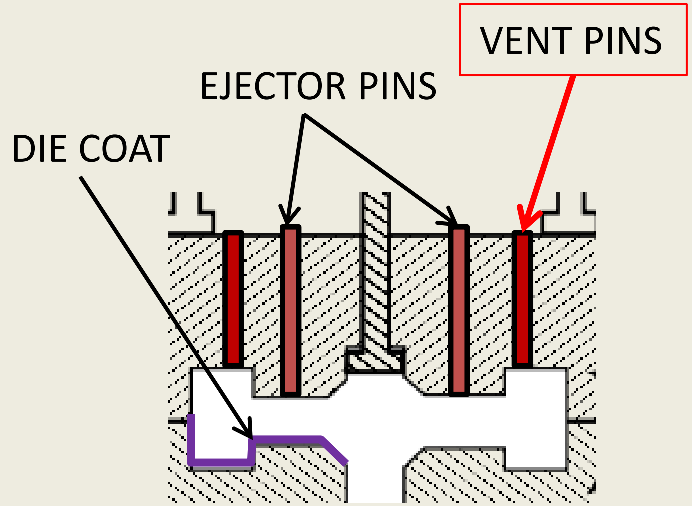


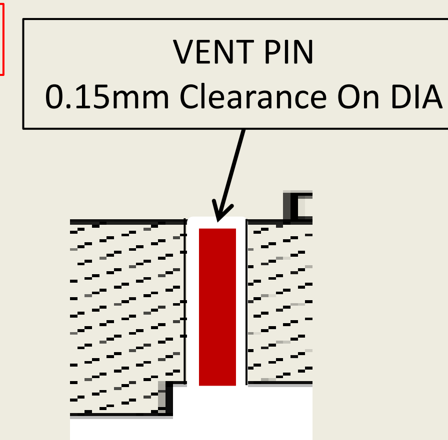


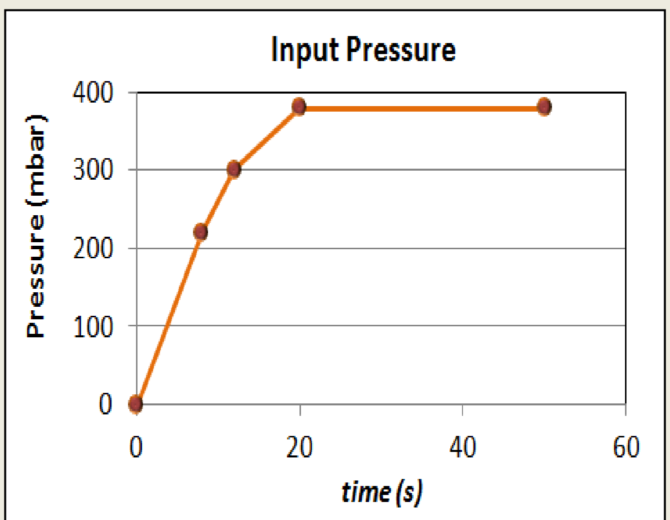


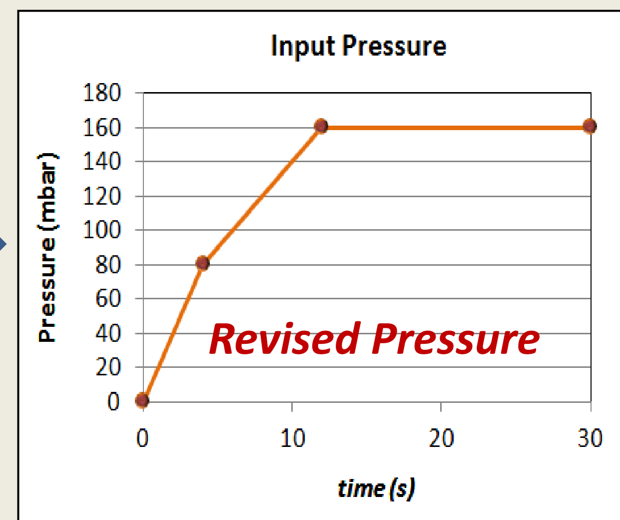
A Closer Look At The LPDC System



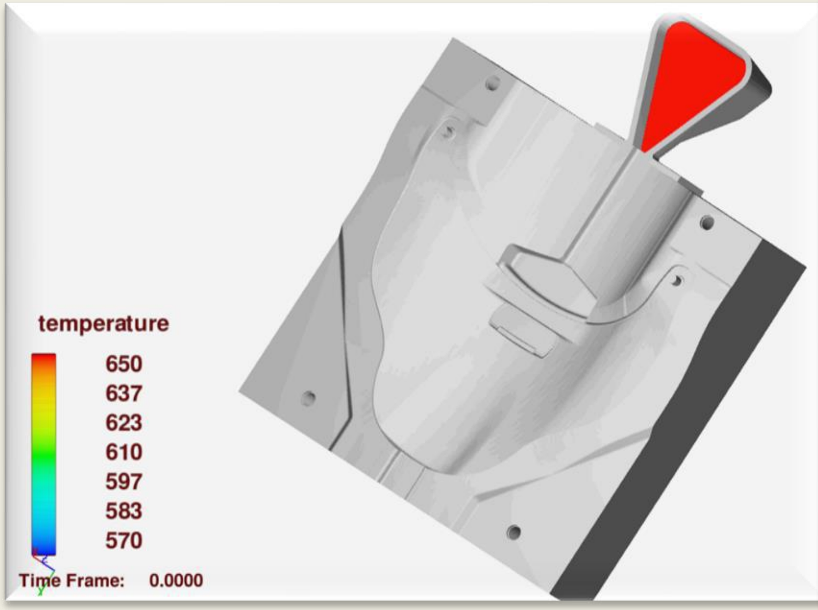


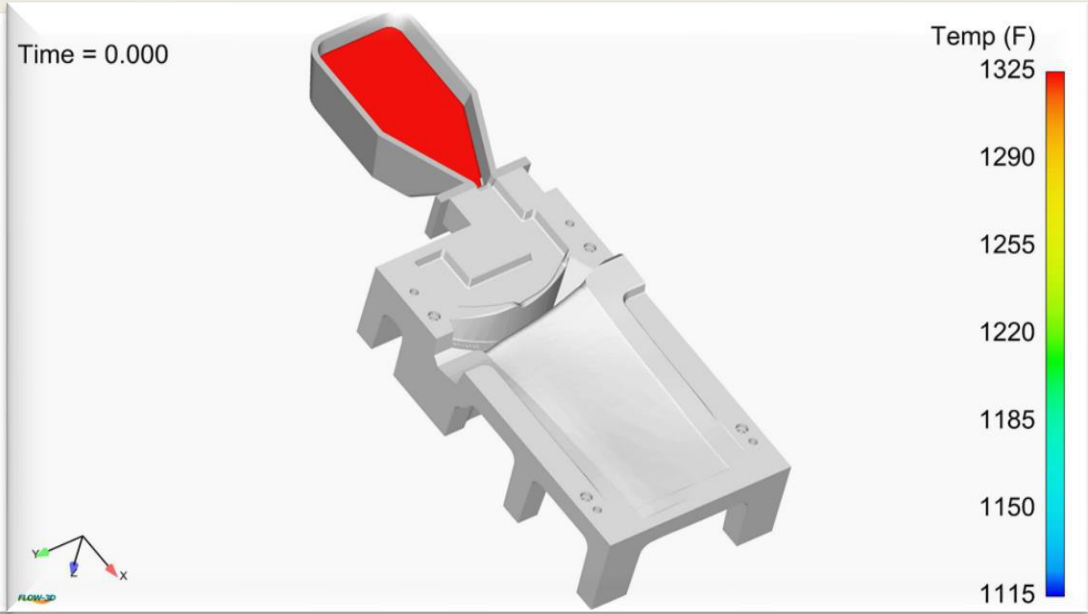


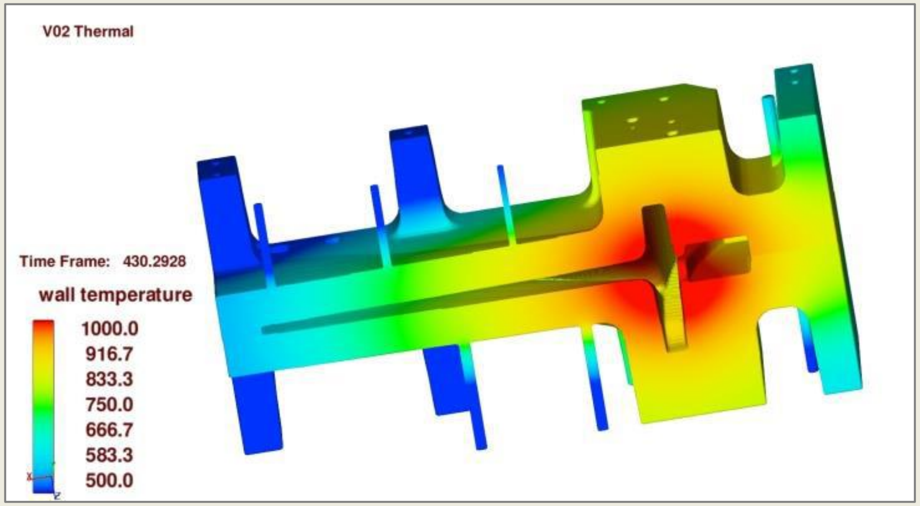




The Goal of Any Casting Process







Steps to successfully capture what happens in LPDC

1. *Find The steady state temperature distribution in the mold – Thermal die cycling*
2. ***Find the thermal resistance of the die coat** – this is the key to capture what happens during the filling stage. Iterative simulations is the easiest way "calibrate" this value.*
3. *Simulate the flow – tilt rate or pressure curve*
4. *Account for all vents*
5. *Solidification stage is quite straightforward to ensure feed path exist to add more liquid and compensate volume change*

Thank you!

What is a Simulation

- *Laws of physics discovered*
- *Equations derived to obey those laws*
- *Computer solves these equations and predict the outcome of things*

We can regard the Laws of physics are absolutely true for every day life – including die casting.

If you find accurate solutions to these equations and define the problem correctly, then you can bet that the predictions will happen.

Common sources of errors:

1. *Measurements or misinterpretation of data measured in the foundry*
2. *Human error: Incorrectly interpreting the laws of physics and forming beliefs that are different from reality*
3. *Human errors: In assessing what the results of simulations mean (e.g. Too much turbulence)*
4. *Human errors in deciding what to do*